Universitetet
i Stavanger
Det teknisk-naturvitenskapelige
fakultet
4036 Stavanger

BPG150

Geofysiske metoder i petroleumsvirksomheten

Geophysical methods applied to petroleum

Solutions key / Fasit

Avsluttende eksamen

Final Examination

24.11.2011

13.00 – 16.00

Hjelpemidler: kalkulator, ordbok

Supporting materials: calculator, dictionary

Answer 4 whole questions out of 5.

Percentage weights are indicated.

Write as much as possible in these exam pages; back sides are okay too.

Write in either English or Norwegian.

Some formulae are listed at the end.

Faglærer/Instructor: R.J. Brown

25% 1. Seismic

An explosive source is detonated at the surface of the Earth, with geophone receivers deployed also at the surface, in an area where there has been cyclic deposition of horizontal layers of carbonates and evaporites. This means that layers 1, 3 and 5 are limestone and have identical properties while layers 2, 4 and 6 are identical salt layers.

All the layers are 150 m thick. The limestones have V_P = 4500 m/s and ρ = 2490 kg/m^3. The salt has V_P = 4500 m/s and ρ = 2100 kg/m^3.

4% (a) Determine the vertical-incidence reflection coefficient, R_2, for a downward-travelling P-wave reflecting at the top of layer 2 (bottom of layer 1).

Since $V_1 = V_2$

~~$R_2 = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} = \frac{2490 - 2100}{'' + ''} = \frac{390}{4590} = 0.0850$~~

$$R_2 = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} = -\frac{390}{4590} = -0.0850$$

3% (b) Determine the corresponding reflection coefficient, R_3, at the top of layer 3.

$$R_3 = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} = -R_2 = +0.0850$$

4% (c) Determine the vertical-incidence transmission coefficient, T_2, for a P-wave travelling downward through the boundary from layer 1 to layer 2.

$$T_2 = 1 - R_2 = 1 + 0.0850 = 1.085$$

3% (d) Determine the vertical-incidence transmission coefficient, T_2', for a P-wave travelling upward through the boundary from layer 2 to layer 1.

R_2' (for refl'n from below at 1-2 interface) $= -R_2 = 0.0850$

$T_2' = 1 - R_2' = 0.915$

4% (e) Which of these two rocks obeys more closely the Gardner relationship between ρ and V_P – the limestone or the salt? Support your answer with some calculation.

Gardner: $\rho = 310 V_P^{0.25}$. For both, V_P = 4500 m/s.

Then ρ = 2539 or 2540 kg/m^3

closer to that of LS. I.e. LS obeys more closely.

7% **(f)** If we assume the limestone to be composed only of calcite (ρ = 2710 kg/m^3) and brine (ρ = 1030 kg/m^3), find the porosity, ϕ, of that limestone. Give ϕ to three figures.

For LS, $\rho = 2490\ kg/m^3$ 2 for 2684

$2490 = (1-\phi)\,2710 + \phi\,(1030)$

$\phi\,(2710 - 1030) = 2710 - 2490$

$\phi = \frac{220}{1680} = 0.1310 = 13.1\%$

25% 2. Seismic, gravity, electrical

3% **(a)** Consider again the same geology and same survey as in Question 1. For the reflection from the top of layer 4 (bottom of layer 3) find the zero-offset 2-way traveltime.

$z = 3 \times 150 = 450\ m$, $V = 4500\ m/s$

$t_0 = \frac{2z}{V} = \frac{900\ m}{4500\ m/s} = 0.2\ s = 200\ ms$

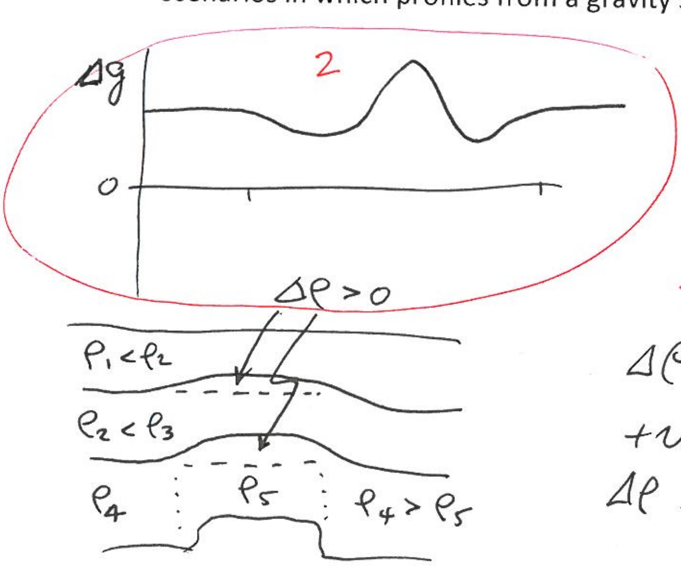
5% **(b)** For the same situation find the traveltime for the same reflection (from the top of layer 4) at an offset of 500 m. What is the normal moveout in this case?

$t^2 = t_0^2 + \frac{x^2}{V^2} = 0.2^2 + \frac{500^2}{4500^2} =$

$t = 0.22879 = 228.8\ ms$ (say 229 ms)

$NMO = 229 - t_0 = 28.8$ or $29\ ms$

6% **(c)** Draw a sketch of a sombrero-type gravity anomaly and briefly describe two geological scenarios in which profiles from a gravity survey could show sombrero-type anomalies.



(i) dense cap rock on top of 2 salt plug or dome or diapir

2 (ii) reef where shallow Δρ anomalies due to drape are +ve over reef and, at depth, Δρ is +ve offreef – or +ve onreef

11% (d) The following (very) rough sketches show results of :

– a reflection seismic survey along the profile **AB** (upper left);

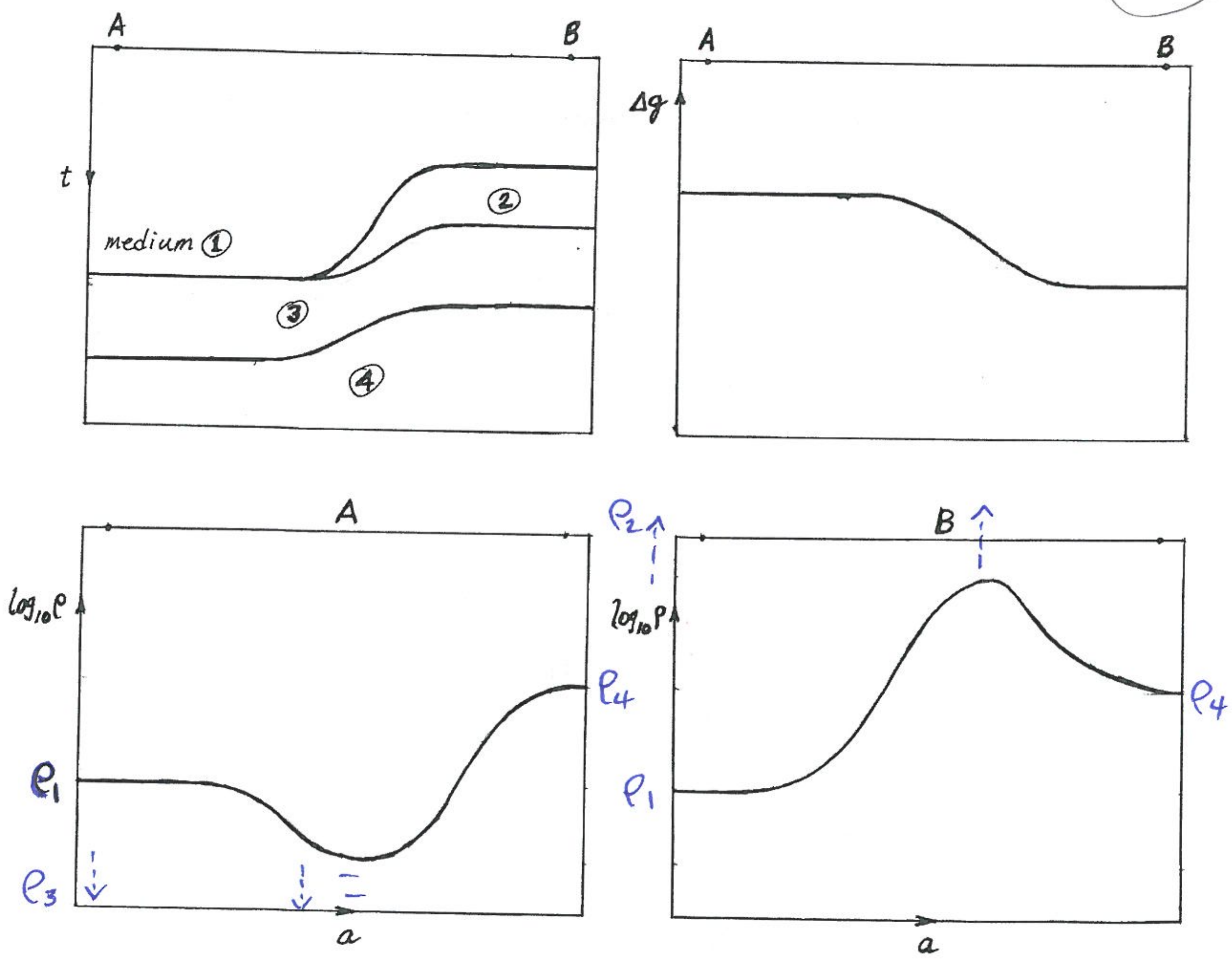
– a Bouguer gravity survey along the same profile (upper right);

– a resistivity survey along a profile centred at **A** and at right angles to **AB** (lower left); and

– a resistivity survey along a profile centred at **B** and at right angles to **AB** (lower right).

In the seismic section, four units or media are numbered (1), (2), (3) and (4). In the resistivity surveys, the parameter a quantifies the electrode separation. A well at **A** tells us that (1), (3) and (4) are sedimentary rocks with brine-filled pore space. A recent well at **B** tells us that unit (3) is flat, i.e., its top and bottom surfaces have constant depths along the profile **AB**. From all this information, what would you conclude about medium ~~(3) in~~ terms of its physical properties (V_P, density, resistivity) and its lithology (i.e. rock type)? State how this conclusion is supported by (or is consistent with) all three types of geophysical data.

2



Medium (2) is

3 – less dense than Med. (1) [due to Δg]

3 – of higher V_P than Med. (1) [due to pull-up]

3 – of higher ρ than any of Med. (1), (3) or (4)

2 – could be salt (or other evaporite – low ρ, ~0 porosity, high V_P)

25% 3. Seismic

5% (a) We are doing a reflection seismic survey in an area where we want to be able to resolve reefs with a width of 500 m at depths of 3 km.

(i) What limiting dominant frequency (to the nearest Hz) will we need to do this? Assume an average velocity between the surface and 3 km depth of 3330 m/s.

(ii) "Limiting" means that it is either the highest or the lowest frequency we can use for resolution. Is this limiting frequency (found above) the lowest or the highest?

(i) $W_F = (2\lambda z)^{1/2}$ = Fresnel-zone w. (diameter)

$\lambda = \frac{V\ m/s}{f\ \cdot/s} = \frac{3330}{f}$, $W_F = 500\ m$

3

$500 = \left(\frac{2 \times 3000 \times 3330}{f}\right)^{1/2} \Rightarrow f = \frac{6000 \times 3330}{500^2} = 80\ Hz$ (= 79.92 Hz) to nearest Hz (80 Hz) ✓

2 (ii) For resolution we can use this f, 79.92 Hz, or anything higher. I.e. $f \geq 80\ Hz$

5% (b) For the same survey as in part (a), we will apply a high-cut filter to our data so that we keep only frequencies up to 1.5 times this limiting frequency [found in part (a)]. We have a seismic recording instrument on which the sampling interval can be set at 0.5 ms, 1 ms, 2 ms, 5 ms or 10 ms. What sampling interval should we choose in order to avoid aliasing and to keep the dataset as small as possible?

Keep $f \leq 120\ Hz$ — $f > 120\ Hz$ filtered out. 1

We need sampling freq., f_s, ∋ $f_s \geq 240\ Hz$ (samples/s)

I.e sampling interval δt_s ∋ $\delta t_s \leq \left(\frac{1}{240}\right) s$ 1½

or $\delta t_s \leq 0.00417\ s \approx 4\ ms$

∴ We can use 0.5 ms, 1 ms or 2 ms; BUT to keep dataset small: $\delta t_s = 2\ ms$ 1½ 1

4% **(c)** In spite of our best efforts with the antialias filter, some noise at twice the limiting dominant frequency has leaked into our dataset, due to an instrumental flaw. At what frequency will this noise be aliased, given your choice of sampling frequency?

Noise at 160 Hz 1

f_N for $\delta t_S = 2$ ms or 0.002 s or $f_S = 500$ Hz

i.e. $f_N = 250$ Hz 1½ so noise NOT aliased 1½

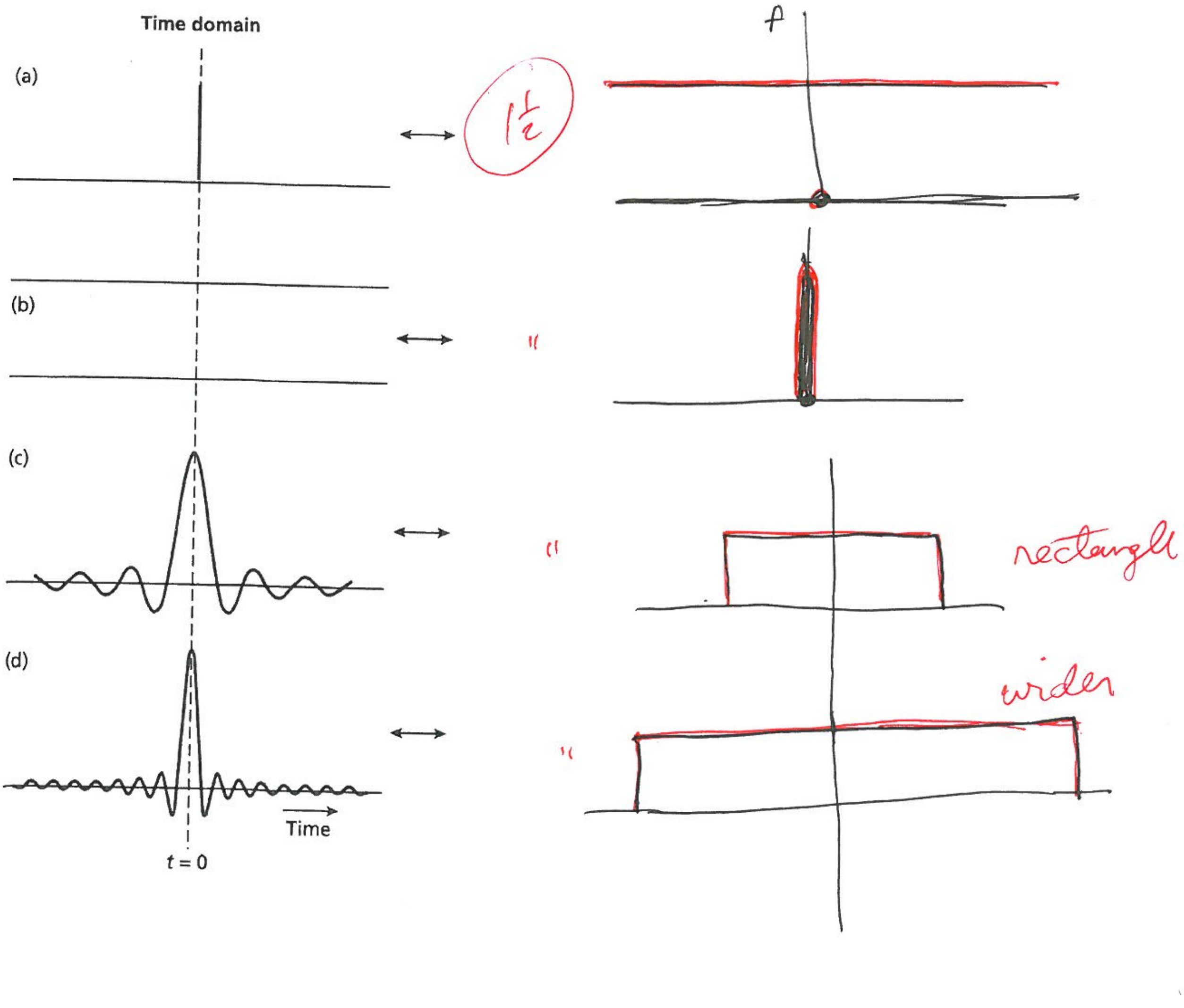
5% **(d)** If we wish to have a dynamic range of 90 dB, how many bits-per-word do we need?

$DR = 90\,dB = 20 \log_{10}\left(\frac{A_{max}}{A_{min}}\right)$ $\quad A_{min} = 1$

$\log_{10}(A_{max}) = 4.5 \Rightarrow A_{max} = 10^{4.5} = 31{,}623$, (2) which we need to be able to express in base 2. $2^{15} = 32768$ (1)

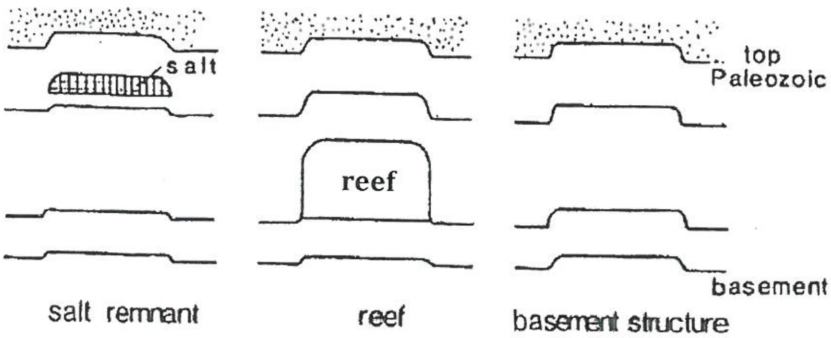
So we need 15 bits to express A_{max} (2)

6% **(e)** The following figure shows four wavelets or functions in the time domain. For each one, sketch a reasonable amplitude spectrum, i.e. in the frequency domain.



25% 4. Gravity, magnetics, seismic

9% (a) Parallel updoming structures like those shown below are observed on a seismic section in a frontier area where there is not a lot of geological information, but where there is magnetic and gravity coverage. Explain briefly how we could combine the magnetic and gravity information to help decide among the three geological possibilities shown.



If salt, look for (−ve) g low; and small mag low

reef, ±0 small g +ve or −ve; mag ~ zero

basement, (+ve) g high; mag also high (+ve)

6% (b) Explain briefly for each of these three cases, shown on the previous page, why the updoming form often repeats itself in a nearly parallel way on seismic reflectors above or below the expression of the primary structure (the salt remnant, the reef, the basement high) associated with the updoming.

salt – 1. collapse above to sides of salt remnant
2. vel'y pull-up below

reef – 1. diff'l compaction above reef
2. maybe pull-up; maybe real high

basement 1. maybe diff'l compaction above
2. " reactivation of faulting above horst

4% **(c)** List 4 types of data correction that are usually applied in gravity data reduction.

1. drift
2. latitude
3. elevation or free-air
4. Bouguer or slab

3% **(d)** List 3 other data corrections that are not so commonly applied in gravity data reduction.

1. Eötvös
2. terrain
3. tidal

1% **(e)** State 1 type of data correction that usually is applied in magnetic data reduction.

1. diurnal

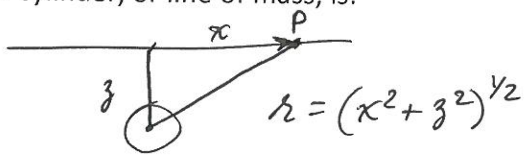
2% **(f)** State 2 other magnetic data corrections that are not so commonly applied in data reduction.

1. terrain
2. geomagnetic
3. elevation

25% 5. Gravity, magnetics

6% **(a)** The expression for Δg for an infinite horizontal cylinder, or line of mass, is:

$$\Delta g = \frac{2G\mu z}{r^2}$$



where μ is mass per unit length. Derive the relationship connecting anomaly width and depth of body for this case. Don't just write the relationship down – derive it. And make sure that you define or explain the meaning of each symbol in your relationship.

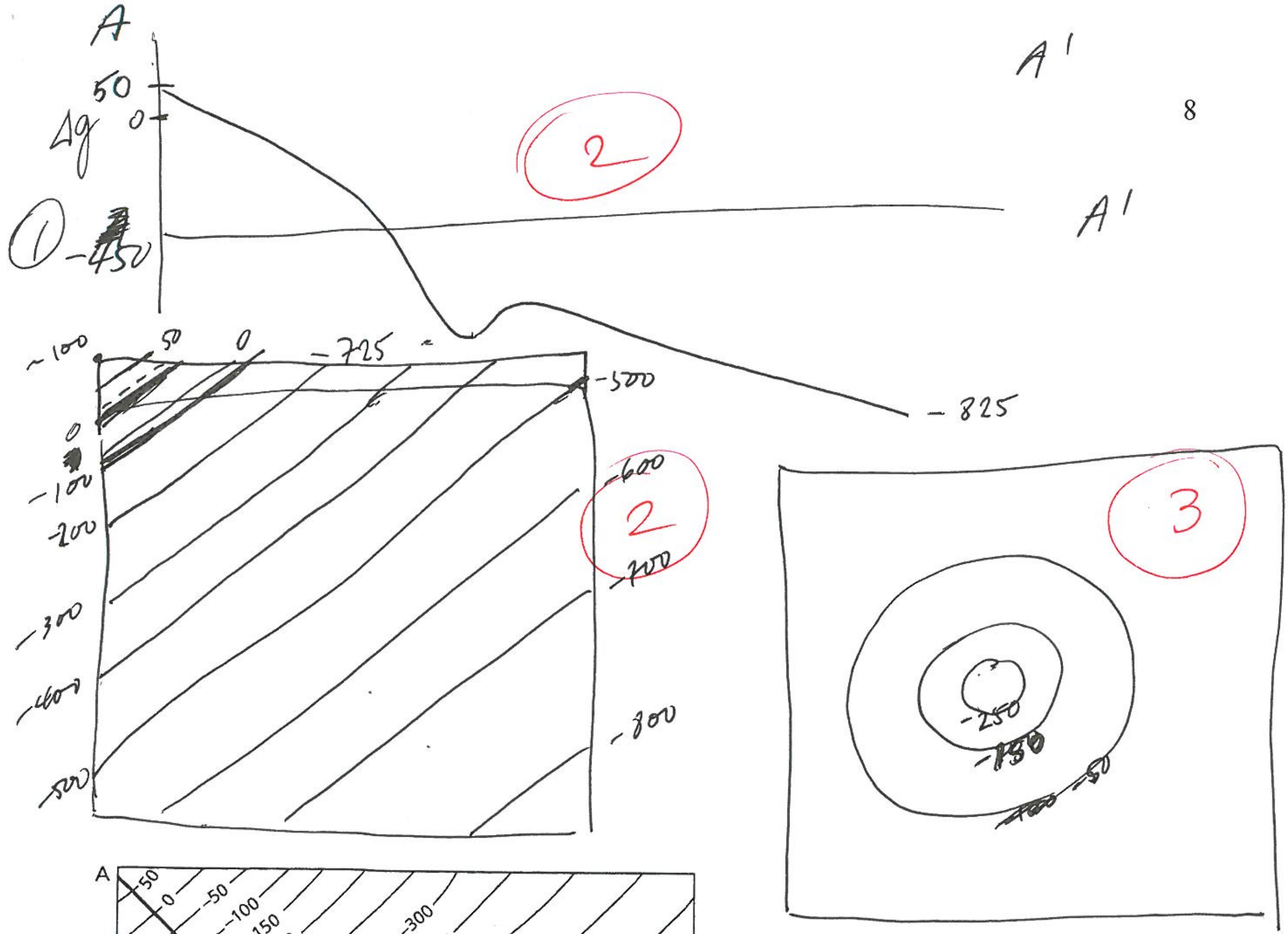
$$\Delta g(x) = \frac{2G\mu z}{x^2+z^2} \Rightarrow \Delta g_{max} = \Delta g(0) = \frac{2G\mu}{z}$$ 1½

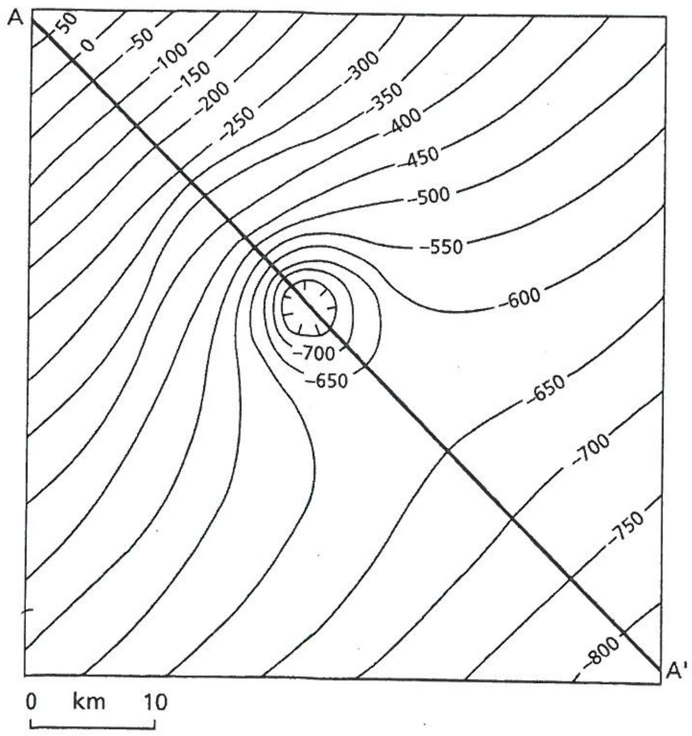
When $\Delta g = \frac{1}{2}\Delta g_{max}$ we say $x = x_{1/2}$

$$\Delta g(x_{1/2}) = \frac{1}{2}\Delta g_{max} = \frac{G\mu}{z} = \frac{2G\mu z}{x_{1/2}^2 + z^2}$$ 2½

$$\Rightarrow 2z^2 = x_{1/2}^2 + z^2 \Rightarrow x_{1/2}^2 = z^2 \text{ or } x_{1/2} = \pm z$$ 2

7% **(b)** The following figure shows a contour map from a gravity survey. Draw three sketches:
(i) showing the profile AA′,
(ii) showing a reasonable map of the regional field, and
(iii) showing a reasonable map of the residual field.



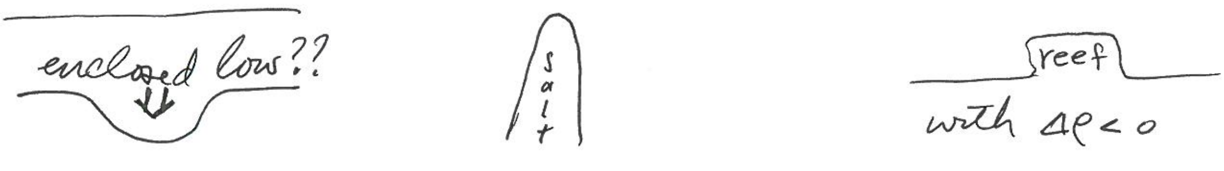


6% **(c)** Give a reasonable example of a geological feature – in terms of lithology and approximate shape – that could cause the anomaly in the middle of this survey area.

Δg is -ve and circular in plan view

Could be

low: 1



3% **(d)** Where on the Earth could we observe a magnetic inclination of ±90°? Be specific.

At the magnetic N or S dip pole.
(Not geomagnetic pole)

3% **(e)** Where inside or outside the Earth does the geomagnetic field originate? Be specific.

In the outer core (where ∃ molten Fe).

Some geophysical formulae:

$$F = \frac{Gm_1m_2}{r^2}$$

$$\rho = 310V_P^{0.25}$$

$$t^2 = t_0^2 + \frac{x^2}{V^2}$$

$$t \approx t_0 + \frac{x^2}{2V^2t_0}$$

$$V_P = \left[\frac{K + \frac{4}{3}\mu}{\rho}\right]^{\frac{1}{2}}$$

$$V_S = \left[\frac{\mu}{\rho}\right]^{\frac{1}{2}}$$

$$\frac{1}{V} \approx \frac{\phi}{V_f} + \frac{1-\phi}{V_m}$$

$$V_{rms,\,n} = \left[\sum_{i=1}^{n} V_i^2 t_i \Big/ \sum_{i=1}^{n} t_i\right]^{\frac{1}{2}}$$

$$V_a = \frac{V}{\sin i}$$

$$V = \lambda f$$

$$DR = 20\log_{10}\left[\frac{A_{max}}{A_{min}}\right]$$

$$R_2 = \frac{\rho_2V_2 - \rho_1V_1}{\rho_2V_2 + \rho_1V_1}$$

$$w_F = (2\lambda z)^{\frac{1}{2}}$$

$$fold = \frac{N}{2n}$$